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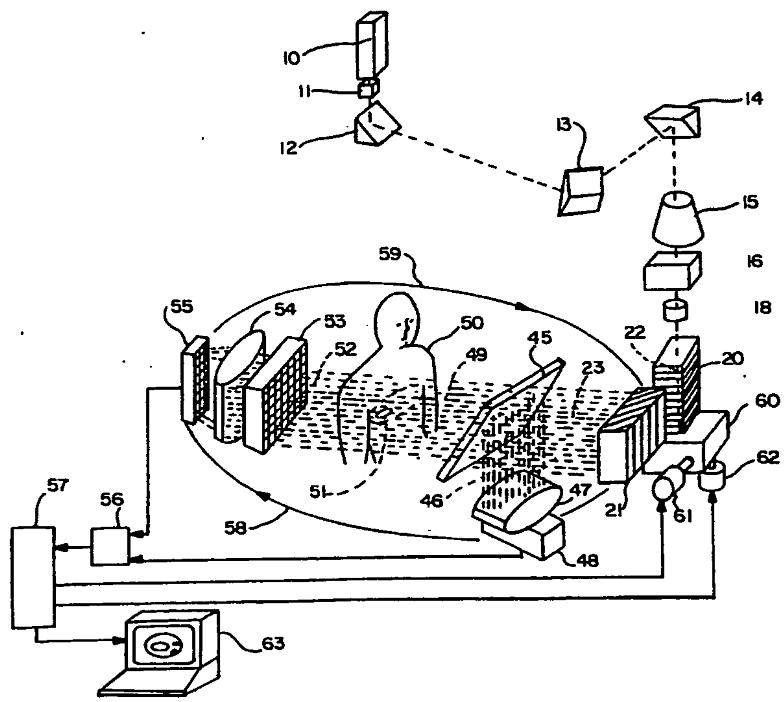
(57) Abstract

Tomographic imaging of the internal structures of bodies (50) based on transparency variations is achieved by illuminating the body with a bundle of light rays (49) in the near infrared range, arranged preferably in a series of parallel rows, processing the transmitted rays (52) emerging from the body to remove the effects of scattering, detecting (55) the processed rays in a manner specific to their cross-sectional location in the bundle, and repeating the procedure at different angles of incidence to generate simultaneous tomographic images (43) by computerized tomographic techniques.



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INFRARED RADIATION IMAGING SYSTEM AND METHOD

BACKGROUND OF THE INVENTION

This invention relates to three-dimensional imaging, and particularly to an infrared radiation based imaging system and method. The invention is of particular interest in the use of infrared radiation for the study of human and animal bodies for analysis, diagnosis, and pharmaceutical investigations and studies.

The concept of using visible light transmitted through animals and humans as a medical diagnostic procedure dates back to Cutler in Transillumination as an aid to diagnoses of breast lesions, Surgery, Gynecology and Obstetrics, 48, 721-727, 1929. Even prior to this light (or transillumination) had been used for medical examination of thin sections of the body such as sinus cavities, the scrotum, ears, etc.

Probably one of the earliest commercial applications of transillumination was to egg candling. Some small fishes are almost completely transparent and studies of digestion processes in these provide an interesting scientific background.

Medical applications of transillumination include the diagnoses of hydrocephalus in infants. Hydrocephalus

is an abnormally large amount of cerebrospinal fluid in the cranium. U.S. Patent No. 3,674,880 and U.S. Patent No. 3,527,932 describe a clinical procedure using transillumination for the diagnoses of hydrocephalus. In this procedure a light source such as a flashlight is placed next to the infant's skull and the level of transmitted light is noted. Normal heads are relatively poor light transmitters relative to heads which contain significant amounts of fluid. Early diagnoses and treatment of the hydrocephalus condition is important for the prevention of mental retardation. Other patents relating to the use of transillumination are U.S. Patent Nos. 2,161,688 and 3,769,963.

Transillumination has been utilized for breast examinations ever since Cutler showed its advantages in cancer detection in 1929. More recently, the term diaphanography (DPG) has been utilized to describe transillumination of the breast to provide detection of diseases of the breast especially breast cancer. The basis of DPG is the differential absorption and differential scattering of light and infrared (IR) radiation by the different breast tissues. Benign and carcinomic tumors tend to absorb more visible and more IR light. These will generally appear as darkened areas in DPG. In addition, arteries and veins are readily visualized in the DPG procedure. Frequently DPG is utilized as a screening procedure. If a suspicious region is observed, further diagnostic procedures may include ultrasonic imaging, X-ray imaging, Magnetic Resonance Imaging or CT scanning.

A hand-held torch providing a suitable light source for DPG is now commercially manufactured, Sinus Medical Equipment AB, Norrlandsgaten 31-33, 11143

Stockholm, Sweden. The torch consists of a tungsten filament bulb, a xenon flash tube, and a cooling fan. D.J. Watmough, A light torch for the transillumination of female breast tissues, British J. of Radiology, 55, 142-146 (1982), has shown that using such a light torch with some improvements, one can image a lesion of diameter down to 6 mm. Both IR sensitive photographic film and a silicon vidicon television camera were utilized in these observations.

C. Merritt, Review, Clinical Diaphanography, Its Present Perspective, CRC Critical Reviews in Oncology/Hematology, 2, 1-31, 1985, screened 1500 patients using a transillumination procedure and found 55 with breast cancer. The average size of the carcinoma was 1.7 cm and the smallest detected was 0.5 cm.

Other diagnostic procedures for viewing the interior of the body utilize X-rays, ultrasonic scans, Magnetic Resonance Imaging (MRI), CT scans and Nuclear scans. Each of these systems are widely employed in the major medical centers.

Conventional X-rays are widely utilized, however they provide ionizing radiation with potential patient damage. In addition, soft tissue resolution is poor. The major advantage of conventional X-rays is for diagnosing bone disorders and in chest studies.

Ultrasonic Imaging systems are believed to be harmless to the patient, however these systems do not provide good resolution relative to either the MRI or the CAT scanners. Ultrasonic imagers are utilized widely because they are inexpensive and can rapidly provide images. The low resolution of such scanners does

limit their usefulness in many medical diagnoses. The Magnetic Resonance Imager (MRI), has become a very significant medical diagnostic system. MRI has the advantage of providing no ionizing radiation to the patient, and produces medical images which resolve tissue images to approximately two to three millimeters diameter. The disadvantages of MRI are the substantial cost, the fact that one cannot image patients with internal magnetic prosthetic devices, the substantial space requirements, and the extensive maintenance needs.

The Computer Assisted Tomography scanner, (the CAT scanner), provides good tissue resolution, but does have the disadvantage of using X-rays which, along with all other ionizing radiation, can cause tissue damage.

Nuclear Medicine Scanners are limited to the diagnoses of a few special diseases, where they are very valuable. They employ ionizing radiation, and are not used for general imaging studies.

The significant advantages of an infra-red based imaging system is that it answers the needs of medical imaging systems in a special way. It provides imaging without the use of ionizing radiation, and without the elaborate installation facility requirements and high cost of the MRI systems. At the same time, the resolution is equal to the CAT and MRI systems so that medical diagnoses can be accomplished in an inexpensive and portable system.

SUMMARY OF THE INVENTION

In accordance with the present invention, imaging is achieved by illuminating an object with a bundle of light rays consisting of electromagnetic radiation within the near infrared range; separating out the transmitted rays which are not the result of scattering; individually detecting these transmitted rays in a manner specific to their cross-sectional location in the bundle; and repeating the process at different angles of incidence to generate a signal combination capable of manipulation by computerized tomography techniques to form tomographic images. The bundle of light rays may range from a continuous beam, in which the rays are defined as contiguous geometrical sections of the beam, to a cluster of discrete rays of small cross-section separated from each other by gaps. In preferred embodiments, the bundle is a two-dimensional array of parallel rows of light rays capable of generating a plurality of tomographic images simultaneously.

The invention has application to internal imaging of almost all non-metallic objects, with a wide range of utility and types of information generated, including both medical and industrial applications. For example, the invention may be applied to integrated circuits for purposes of testing, analysis and quality control. It may also be used to control the quality, type and selection of such material as wood and plastics, by detecting porosity, blow holes, knot holes and other imperfections. A further application is food grading, in which density may be determined and inhomogeneities detected. Similar determinations may be made in chemical and petroleum products in general. Medical imaging is the most important of the

potential applications of the invention, where the images produced by the invention reflect different types of tissue structures in biological bodies in a diagnostically useful manner.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a diagram of one example of an imaging system in accordance with the present invention.

Figures 2A, 2B and 2C are representations of alternative methods for converting a single incident beam into a series of parallel beams.

Figure 3 is a diagram of a second example of an imaging system in accordance with the present invention.

Figure 4 is a diagram of a third example of an imaging system in accordance with the present invention.

DETAILED DESCRIPTION OF THE INVENTION AND PREFERRED EMBODIMENTS

Basic steps in the practice of the present invention include the formation of a light ray bundle; the transmission of the bundle through a subject body; the detection of rays transmitted through the body after removal of scattering; the rotation of the light ray bundle to repeat the transmission and detection at different angles of incidence; the storing of the detection signals after each transmission; and the combination of the stored signals in accordance with an algorithm to form images of tomographic slices of the body defined by the traversing rays.

As used herein, the term "light ray" is intended to mean any beam of light whose intensity level averaged over its entire cross-sectional area translates into one picture element ("pixel") in the final image. The size of the cross-section will determine the resolution of the image, and may be tailored accordingly to suit the type of body being studied and the size and shape of the irregularities or internal features expected to be found. The size of each ray may thus vary widely. In medical applications, rays having a width or a diameter of about 4 mm or less, preferably about 3 mm or less, will provide the best results. A single ray may comprise a spatial division of a single continuous beam, or in the alternative, may be discrete, i.e., not connected or contiguous with neighboring rays. In the former case, the ray is the smallest cross-section of the beam which is resolved in the final image.

The wavelengths are in the near infrared range. The optimal wavelength in each case will vary with the

nature and quality of the material to be penetrated as well as the range of variations of transparency within the subject body. In general, wavelengths ranging from about 0.7 to about 5.0 microns will be used. For biological bodies, particularly human bodies, preferred wavelengths are those ranging from about 0.7 to about 1.6 microns. These are termed near infrared or infrared waves.

The incident beam must be of sufficient intensity to penetrate and be transmitted through the body so that variations in the intensity of the transmitted light due to the different types of tissue or materials in the body transversed by the beam can be detected. This can vary widely, and will depend on the thickness and density of the body, the cross-sectional area of the body to which the beam is being exposed, and the sensitivity of the detection medium. In most applications, an intensity of the entire bundle or beam ranging from about 0.5 watts to about 100 watts will provide the best results.

In the context of this invention, the term "bundle" is used to denote a group of rays in close proximity penetrating a subject body at the same time for simultaneous detection upon emergence. The rays in the bundle may be contiguous or discrete, and form at least one straight row. Preferably, the bundle is a two-dimensional array of rays, most preferably rectangular, arranged in a series of parallel rows. The bundle may be either of constant cross-section or fan-shaped. Fan beams are those with a rectangular cross-section widening in the direction of transmission along the axis parallel to the rows.

The bundle may be formed from rays emanating from individual sources. Most conveniently, however, the bundle is formed from a single ray which is separated into a multitude of rays by a combination of reflection, refraction and transmission through mirrors, prisms and/or lenses. A two-dimensional array may be formed by using two such arrangements in series, one rotated 90° with respect to the other.

The light may be generated by any source which is capable of focusing a beam of the appropriate wavelength and intensity. Light sources capable of producing a substantially monochromatic beam, i.e., one with a wavelength spread of approximately 1 Angstrom or less, are preferred. Monochromatic beams are preferable for purpose of scatter filtering, and are particularly important where high resolution and tomographic techniques are used. Lasers emitting radiation of the appropriate wavelength and intensity are particularly appropriate. Examples are crystal solid state, ion, gas and solid state diode lasers. In addition, dye lasers, and Nd:YAG and other gas and rare earth solid state lasers provide appropriate wavelengths. Lasers with frequency doublers or tunable lasers such as some of the dye lasers are applicable to the present application.

In some cases the heat generated in the subject by absorption of the penetrating light may be sufficient to cause discomfort or tissue damage. This may be alleviated by cooling to remove heat from the subject during the exposure. This may be done by conventional means such as, for example, submersion in a cooling medium such as water or application of a protective skin preparation, which can also be made to serve the

purpose of improving light transmission by matching the refractive indices at the interface.

The detection of emerging rays in accordance with the invention is substantially limited to rays passing straight through the subject body without reflection, refraction or scattering. The emerging rays are thus collimated prior to reaching the detectors. Small angle scattering may be included with the detected rays, depending on the ray and detector cross-sections and the length of transmission. All other transmissions are prevented from reaching or being detected by the detectors.

Collimation may be accomplished in any of several ways. Examples include: the use of non-reflecting light transmission pipes between the body and the detectors, each pipe corresponding to and sized to accommodate exactly one ray. The pipes will generally have a square or rectangular cross-section; the use of aligned holes in two or more planes of light-absorbing material; separation of the light rays by one or more transverse planes between the body and the detectors; and the use of different wavelengths in adjacent rays. The individual detectors may then be tuned to respond only to the wavelengths of the corresponding incident rays. This may be done by the use of filters or other conventional means.

When a procedure according to example 3 is employed, transmissions must be repeated after shifting the incident rays laterally with respect to the subject body in a parallel shift, so that they penetrate the regions which were formerly gaps. The total number of shifts required to fill in all gaps and thus encompass the entire region will depend on the ratio of gap

width to ray width. With gaps of equal spacing along both axes of the cross-sectional plane and a width ratio of n (an integer) with a square array, a total of $(n + 1)^2$ transmissions will be required. A full scan for each shift will be required to complete the image.

Scattering may also be eliminated by the use of photodetectors programmed to accept light signals only at certain times or at certain modulation frequencies to correspond to source rays in direct alignment, thereby rejecting those rays impinging on them as the result of scattering from neighboring source rays. The source rays are accordingly emitted at different times by rapid on/off switching between adjoining rays, or all modulated by the use of shutters, Pockels cells or similar devices capable of periodic on/off switching or intensity variations. In the latter case, adjoining rays are distinguished by differing modulation frequencies as are the corresponding photodetectors.

The detection system is comprised of a series of individual elements, arranged in an array corresponding to the incident bundle. In preferred embodiments, this is a two-dimensional array of photodetectors, which may include conventional photoconductive and photovoltaic detectors sensitive to infrared radiation. Examples include photomultipliers, silicon photodiodes, transistors, avalanche photodiodes, charge coupled devices, gallium arsenide photocathodes, detectors based on compounds of silicon, phosphor, germanium, antimony, or bismuth, and other vacuum and semiconductor photodetectors well known in the art.

The imaging subject may be conceived as being divided into a set of hundreds of parallelepipeds with each parallelepiped being traversed by a single ray. The difference in ray transmission through adjoining parallelepipeds determines the resolution of borders or irregularities within the subject. Therefore, detection of adjoining ray intensity differences is particularly important in obtaining high resolution images.

Lasers are not intrinsically constant in intensity over time. Therefore several means can be provided to stabilize the laser intensity over time. One method is to use an intensity stabilizer which senses the beam intensity with a photodetector, amplifies the sensed voltage and provides a feedback signal to the laser power source or a beam valve (such as a Pockels cell) to stabilize the laser intensity. Another form of stabilization is to switch the laser rays rapidly so as to traverse neighboring parallelepipeds in the subject and thereby average out the intensity fluctuations. The switching of the beam also provides another advantage which is that ray scatter from one parallelepiped to the neighboring parallelepiped will be rejected by the detection photodetector because such scatter will occur in different time periods. A third method of correcting for laser intensity fluctuations is to use a comparison between the incident radiation and the transmitted radiation. For example, a small fraction (about 1%) of light emanating from the source may be deflected and directed to an adjoining photodetector, and the resulting signal combined with that from photodetectors preceding the transmitted rays to provide a difference.

Once the transmitted rays have been detected, transmission is repeated at a series of different angles of incidence in accordance with conventional tomographic procedures to obtain sets of signal data corresponding to each angle for ultimate combination and manipulation in the generation of images. The angles generally differ from one another by small increments, preferably at most two degrees and most preferably at most one degree. Increments of one degree or one-half degree are particularly preferred. The aggregate of the angles will preferably be approximately 180°. Angle variation is generally achieved by rotating both the source of the incident bundle and the detector bank. Conventional equipment, such as a computer driven servomotor may be used.

Image construction may then be achieved by conventional computerized tomography techniques, including such manipulations as convolution, inverse Fourier transforms, back projections, and combinations of these.

Turning now to the figures, one type of overall plan for a multi-plane imaging system is shown in Figure 1. Light of appropriate wavelength originates in a source 10, which may be a laser or a bank of lasers. An intensity steadier system 11 is used to stabilize the laser intensity. A series of mirrors or prisms 12, 13, 14 direct the light to a beam expander 15, which may be a set of optical lenses which expand the beam cross-section and then recollimate the beam. The resulting beam is then intercepted by a beam attenuator 16 to control the beam intensity. In order to provide a wave front with a uniform energy density, a set of lenses 18 is placed in the beam path to smooth the wave front energy distribution.

The beam emerging from the lenses 18 is then expanded and/or separated into a two-dimensional array of parallel rays. This is done by a pair of separators 20, 21 which expand the beam out along a pair of perpendicular axes. In the embodiment shown in the drawing the first separator 20 separates the incoming beam into a vertical row of rays 22, while the second separator 21 expands each of these rays horizontally to form a two-dimensional array of parallel rays 23.

Various possibilities for these beam separators are shown in Figures 2A, 2B and 2C. In Figure 2A, the separator is comprised of a stack 25 of glass plates oriented at a 45° angle to the incident beam 26. One face 27 of each glass plate is slightly silvered to produce fractional reflection. As an example, the plates may be silvered to produce about 4% reflection. The plates may be cemented together with a cement such as Canadian Balsam having an index of refraction approximately equal to that of the glass (generally around 1.5), thereby reducing stray reflections and increasing efficiency. The reflected beams 28 from each of the slightly silvered surfaces form a linear array.

In Figure 2B, a series of glass plates 30 are slightly silvered similarly to those of Figure 2A and positioned at a similar angle with respect to the incident beam 31 but separated by gaps. The resulting reflected rays 32 are also separated by gaps, as one method of eliminating scattered rays from those reaching the detectors.

Finally, in Figure 2C a still further alternative is shown. Here, a thick glass plate 34 has one surface fully silvered 35 for total internal reflection, while

the other surface 36 is partially silvered for approximately 95% reflection. The incoming beam 37 is directed at a 45° angle of incidence at a transparent portion 38 of the upper surface. Due to refraction, the portion of the beam transmitted through the glass travels at a 28° angle, and is fully reflected off the bottom reflecting surface 35. Upon reaching the upper surface 36, a portion is transmitted outward 39 while the remainder 40 is again reflected internally. As this continues down the length of the plate, a parallel set of rays 41 emerges.

Returning to Figure 1, the two-dimensional ray bundle 23 produced by the beam separators is intercepted by a partially reflecting mirror 45 arranged at an angle with respect to the direction of transmission. The mirror 45 reflects a portion 46 of the ray bundle through a lens 47 which focuses the reflected rays onto a bank of reference photoreceptors 48 for purposes of comparison with the rays transmitted through the subject body.

The remainder of the ray bundle 23 which is not reflected by the mirror 45 forms the incident rays 49 which pass through the body 50 being imaged. It should be recalled that as a result of the beam separators 20 and 21 the incident rays 49 comprise a two-dimensional array consisting of a series of parallel rows. The intersection of the subject body 50 with each row is a tomographic slice 51, of which only one is shown in the drawing. In reality, a plurality of such slices is defined, parallel and possibly contiguous, depending on whether or not the incident rays are separated by gaps.

Of the transmitted rays 52 emerging from the other side of the body 50 only those emerging in a straight line from the incident rays are shown. Scattered rays are eliminated by a collimator 53. In embodiments where adjacent rays differ in wavelength, the collimator 53 may consist of or incorporate an array of filters as described above for selectively passing rays of appropriate wavelength. A lens 54 focuses the rays on a bank of photoreceptors 55.

Signals from both banks of photoreceptors are directed to a signal processor and analog/digital converter 56 which feeds a set of representative signals to a computer 57 for temporary storage. The signals from both banks of photoreceptors are carefully indexed within the computer so that computations can be carried out using related intensity measurements. One such calculation is the determination of the transmission level of a specific ray divided by the incident level of that same ray. The quotient gives the percentage of the ray intensity which is transmitted. In addition, the computer can be programmed to emphasize transmission levels relative to the average incidence or average transmission, relative to nearest neighbor ray transmission, relative to a normalized level, or relative to other laser wavelengths which can be employed simultaneously (in adjoining regions) or in a sequence of imaging procedures. Use of such different wavelengths provides additional means of resolving and discriminating between elements of the imaged subject.

The computer 57 then directs motors such as servomotors to rotate the system around the stationary nonrotating subject as indicated by the arrows 58, 59, while data is collected at each of a plurality of

points along the way, preferably about 1° or 0.5° increments. The servomotor 60 is this drawing is shown as having coordinates in two orthogonal directions 61, 62. Finally, a display terminal 63 either displays or records the series of images produced by the computer 57 for each tomographic plane 51 in a subject body, utilizing each of the various angles of incidence. Conventional computerized tomography techniques are used in generating the image.

A second type of arrangement for an overall plan for multi-plane imaging is shown in Figure 3. Here again a laser 71 is the source of an IR beam, and reflectors 72, 73 direct the beam through a beam expander 74 which shapes the beam into the desired size. The beam then passes through lens configurations 75 of types well known in the art to even out the power distribution over the beam area and thus render it uniform. The intensity of the beam can be adjusted by a variable attenuator 76 which is computer controlled by a computer programmed signal 77. The beam is then separated by a beam separator 78 which may consist of as many as 100 partially reflecting plates. The separator provides a set of parallel rays which decrease the scatter interference from the object due to their separation. In order to fill in the gaps, a servo or stepping motor 79 is programmed through a computer directed signal 80 to move the beam separator 78 through a space sufficient to fill in the gaps in the parallel rays 81 produced by the beam separator. The servomotor will generally have several steps programmed to fill in the several gaps.

A negative cylindrical lens 82 spreads the rays into fan beams 83 which are then collimated and separated by the collimator 84. It is generally advantageous to introduce gaps in the fan beams 83 orthogonal to those in the parallel beams 81, thereby providing a two-dimensional array of discrete rays. The collimator 84 can provide this separation either by blocking portions of the beam or by using lenses to redirect the beam so that the fan beam shows gaps. The gaps will be filled in later on by moving the collimator with the computer controlled servo or stepping motor 85. The segmented fan beam is shown parallel in the Figure for simplicity.

The fan beam is now partially (a few percent) reflected by a 95% transmission window 86. The few percent sample of the beam then is converged by the lens 87 to the set of photodetectors 88. One photodetector element corresponds to each pixel.

The segmented fan beam 89 passing through the window 86 traverses the subject 90 to be imaged, which it intersects along a series of parallel planes 91. Within the subject 90 there is absorption, reflection, refraction, and transmissions of the IR light. In order to provide good reconstructions, it is best to accept only the emergent rays which have passed straight through, or have only undergone very small angular deviations from the straight-through paths. The acceptor of such rays is the collimator 92 which rejects scattered rays which emerge at any significant angular deviation from the straight-through paths.

The lens 93 converges the rays onto the photodetector array 94 wherein there is a photodetector element positioned to detect each ray element. The

photodetector array is connected by cable to the amplifiers, signal processors, and filters 95. After signal processing, the signals are converted to digital form by the analog to digital converter 96 and fed into the computer (not shown) for the tomographic computation. Similarly, the sampled input IR is connected from the photodetector array 88 to the signal processor 97 and the A/D converter 98. The signal emerging from the latter provides the computer with information regarding both spatial variations and time fluctuations in the intensity of the input beam. The computer will then use this for comparison when manipulating the signals emerging from the transmission side A/D converter 96 to provide improved signal level information as to rays transmitted through the subject 90.

The system of elements 72 through 94 is rotated approximately one or one-half degree and the scan information is then repeated. By carrying out approximately 180 or 360 such scans enough information is obtained to carry out a reconstruction algorithm in the computer as in the Figure 1 embodiment. Such reconstruction algorithms generally utilize Fourier transforms, convolutions and back projections. These techniques are well known in the science and art of image reconstruction.

It is to be noted that the lasers in Figures 1 and 3 are so positioned that they need not be rotated with the system. This is an advantage because it decreases the bulk of the system which will rotate.

It is also feasible to provide a system in which fewer elements of the system rotate. Such a system is shown in Figure 4. Here the only moving part is a

servomotor driven reflector 101, which directs an IR beam from a laser 102 to a convex reflector 103 which is part of a bank 104 of such reflectors arranged in an arc. The convex reflector 103 produces a fan beam 105 directed toward the subject 106 after being separated into spaced-apart rays by an array of electronically controlled slits 107. It is important to note that the fan beam here as well as the one on Figure 3 has a cross-section which expands along one axis only, i.e., the axis parallel to the image planes (in the embodiments shown, the horizontal axis).

Rays transmitted 108 through the subject are collimated by collimating slits 109, and converted to electric signals by a bank of photoelectric detectors 110, arranged in an arc. These signals are in turn processed by a signal processor and analog-to-digital converter 111 which feeds information to a computer 112 and display terminal 113 as in the other embodiments. Transmissions and signals at various angles through the subject 106 are accomplished by rotating the reflector 101 to engage in the convex reflectors 103 one at a time.

It is an advantage to carry out the imaging process with several different wavelengths of laser radiation. The advantage is that some portions of the subject transmit better at some wavelengths than at others. By using several different wavelengths and image subtraction, and/or division, multiplication, averaging, and normalizing techniques, one can obtain emphasis upon desired features of the images by optimizing the resolution of the images within several different transmission ranges. One can thus enhance the detection of normal features, such as the borders between different tissues and organs, as well as

abnormalities such as tissue irregularities and carcinomas, over a wider range.

As a further variation within the scope of the invention, one can use photodetectors capable of accepting and differentiating among several modulation frequencies and emitting a separate signal for each one. This permits transmission throughout the subject body at several different angles simultaneously rather than in succession, thereby speeding up the imaging process.

The foregoing is offered primarily for purposes of illustration. It will be readily apparent to those skilled in the art that numerous variation and modifications of the procedures, parameters and structural elements described herein may be made without departing from the spirit and scope of the invention.

WHAT IS CLAIMED IS:

1. A method of forming a series of tomographic images of a subject body, said method comprising:

(a) forming a bundle of light rays having wavelengths of from about 0.7 to about 5.0 microns, said bundle having a cross-section comprised of at least one row of said light rays, said cross-section ranging from constant to expanding along the axis of said row;

(b) passing said bundle through said subject body;

(c) individually detecting light rays from said bundle transmitted through said subject body substantially free of scattering in accordance with the location of corresponding incident rays in said cross-section;

(d) repeating steps (b) and (c) a plurality of times varying each time the direction of incidence of said bundle while keeping said row in a constant plane;

(e) converting said detected light rays to signals representative of their intensity, position in said cross-section and angle of incidence; and

(f) combining said signals to form an image corresponding to the region of said subject body traversed by said row.

2. A method of forming a series of tomographic images of a subject body, said method comprising:

(a) forming a bundle of light rays having wavelengths of about 0.7 to about 5.0 microns, said bundle having a cross-section comprised of a plurality of parallel rows of said light rays, said cross-section ranging from constant to expanding along an axis parallel to said rows;

(b) passing said bundle through said subject body;

(c) individually detecting light rays from said bundle transmitted through said subject body substantially free of scattering in accordance with the location of corresponding incident rays in said cross-section;

(d) repeating steps (b) and (c) a plurality of times varying each time the direction of incidence of said bundle while keeping each said parallel row in a constant plane;

(e) converting said detected light rays to signals representative of their intensity, position in said cross-section and angle of incidence; and

(f) combining said signals to form a plurality of images each corresponding to the region of said subject body traversed by one said parallel row.

3. A method in accordance with Claim 1 or 2 in which the directions of step (d) collectively span an angle of approximately 180°.

4. A method in accordance with Claim 3 in which the directions of step (d) differ by increments of a maximum of about 2°.

5. A method in accordance with Claim 3 in which the directions of step (d) differ by increments of a maximum of about 1°.

6. A method in accordance with Claim 1 or 2 in which said rays are at most approximately 4mm in width.

7. A method in accordance with Claim 1 or 2 in which said rays are at most approximately 3mm in width.

8. A method in accordance with Claim 1 or 2 in which each said ray is substantially monochromatic.

9. A method in accordance with Claim 1 or 2 in which each said ray is substantially monochromatic and has wavelengths of about 0.7 to about 1.6 microns.

10. A method in accordance with Claim 1 or 2 in which the intensity of said bundle is about 0.5 to about 100 watts.

11. A method in accordance with Claim 1 or 2 in which step (c) includes selectively collimating said transmitted light rays to eliminate scattered rays emerging from said subject body prior to detecting said transmitted rays.

12. A method in accordance with Claim 1 or 2 in which each pair of adjacent light rays in said bundle is separated by a gap of at least the width of one said light ray, and said method further comprises repeating steps (a) through (d) with said bundle shifted transversely a sufficient number of times to fill substantially all said gaps.

13. A method in accordance with Claim 1 or 2 in which each said light ray is substantially monochromatic and each pair of adjacent light rays differs in wavelength by a preselected increment, and step (c) includes passing said transmitted light rays through an array of filters selective for the wavelengths of incident light rays aligned therewith, prior to detecting said transmitted light rays.

14. A method in accordance with Claim 1 or 2 in which step (f) is performed by a computer which further

controls means for selectively collimating both the light rays of step (a) and the transmitted light rays of step (c) and means for varying the direction of incidence of said bundle in accordance with step (d).

15. A method in accordance with Claim 1 or 2 comprising using a plurality of wavelengths in step (a) selected according to the transmission characteristics of a selected plurality of materials within said subject body, and step (f) includes combining the signals resulting from said plurality of wavelengths by some or all of subtraction, addition, normalization, averaging, multiplication and division to optimize the resolution within said images of variations within each of said materials.

16. A method in accordance with Claim 1 or 2 in which said subject body is a living body comprised of a plurality of tissues differing in transmission characteristics, said method further comprising repeating steps (a) through (e) a plurality of times, each time using a different wavelength selected according to a preselected range of transmission characteristics to permit the detection in step (f) of irregularities within each of said tissues.

17. A method in accordance with Claim 1 or 2 in which adjacent incident light rays in said bundle are transmitted through said subject body at different transmission times in step (b), and step (c) comprises detecting transmitted light rays by photodetectors programmed to selectively receive said transmitted light rays at preselected times corresponding to the transmission times of incident light rays aligned therewith.

18. A method in accordance with Claim 1 or 2 in which adjacent incident light rays in said bundle are modulated at different frequencies in step (b) and step (c) comprises detecting transmitted light rays by photodetectors programmed to selectively receive said transmitted light rays at the modulation frequencies of the incident light rays aligned therewith.

19. A method in accordance with Claim 1 or 2 in which the repetitions of step (d) are performed simultaneously using incident light rays modulated at a different frequency for each variation of the direction of incidence, and step (c) comprises detecting transmitted light rays by photodetectors programmed to receive said transmitted light rays and emit a separate signal for each modulation frequency.

20. Apparatus for forming images of the internal tissues of a body comprising:

(a) means for forming a plurality of infra-red light rays, means for detecting said rays transmitted through the body and forming output signals related to the intensity of said received rays;

(b) means for providing a reference signal indicative of the relative intensity of the said received rays by which the relative tissue transmission can be measured.

(c) means for receiving said output signals and said reference signals and combining their intensity values so as to form signals representative of the relative transmissions of the different infra-red light rays.

21. Apparatus as in Claim 20 wherein said means forming a plurality of infrared light rays comprises means for dividing an infra-red light beam into

parallel or fan shaped bundles of rays so as to provide a set of rays.

22. Apparatus as in Claim 21 including means for rotating the angle of incidence of said light rays through a plurality of positions to provide a plurality of signals one for each position and computing means for receiving said signals and providing a tomographic image of the body.

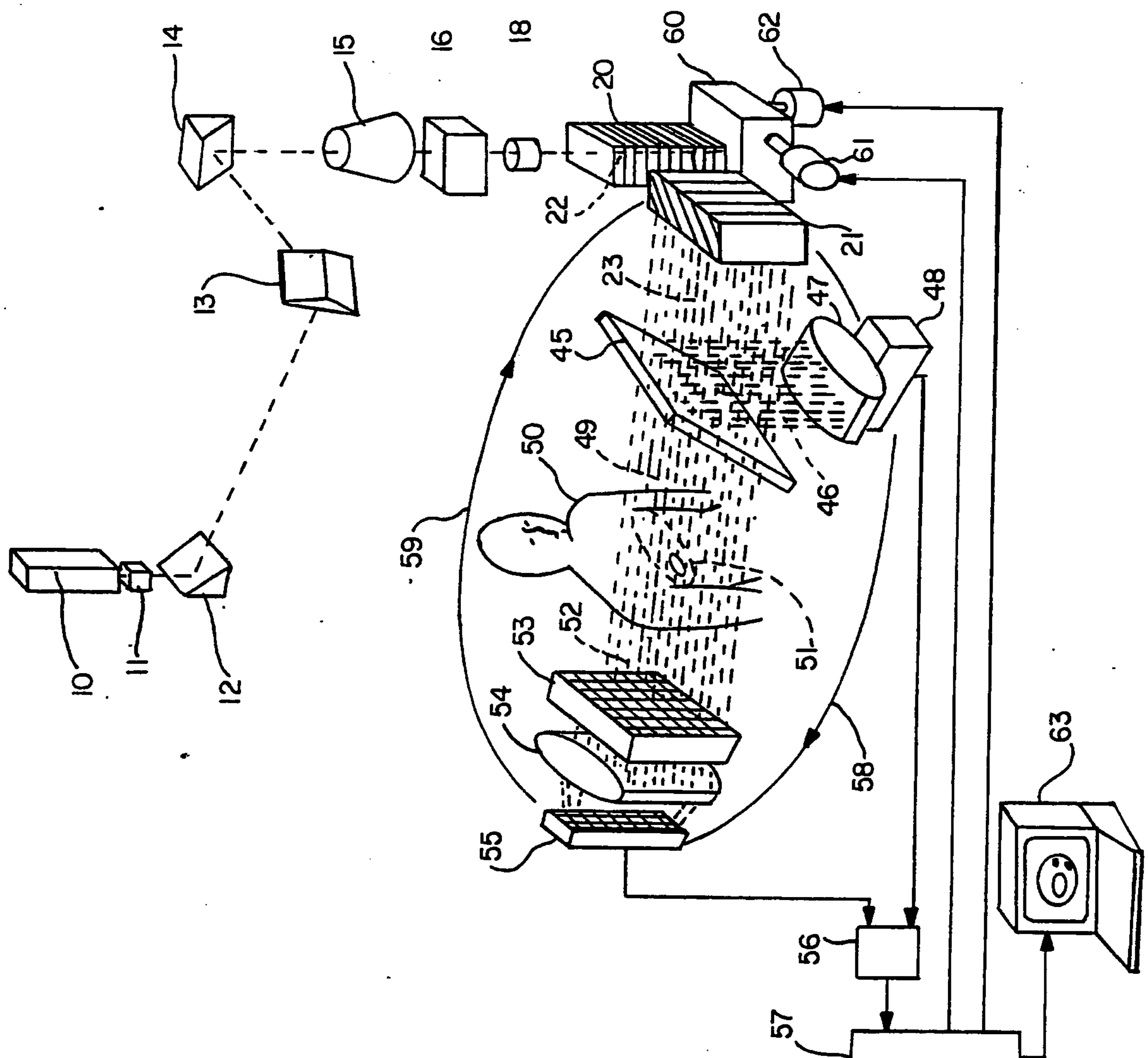
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FIG.—1

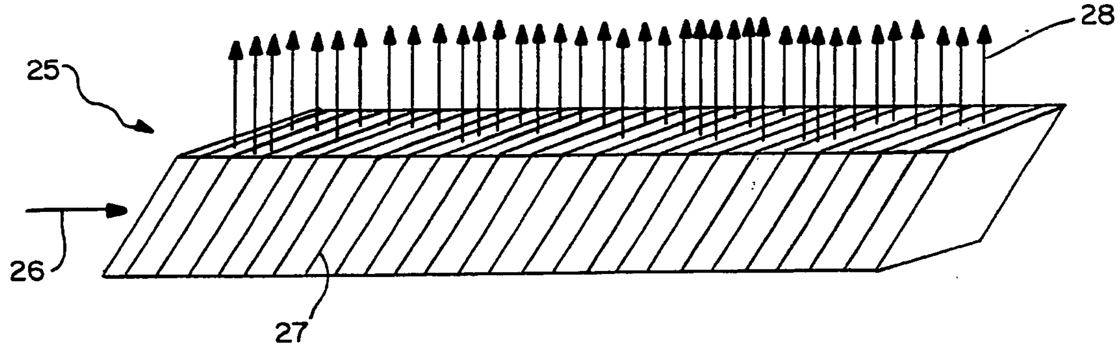

FIG. — 2A

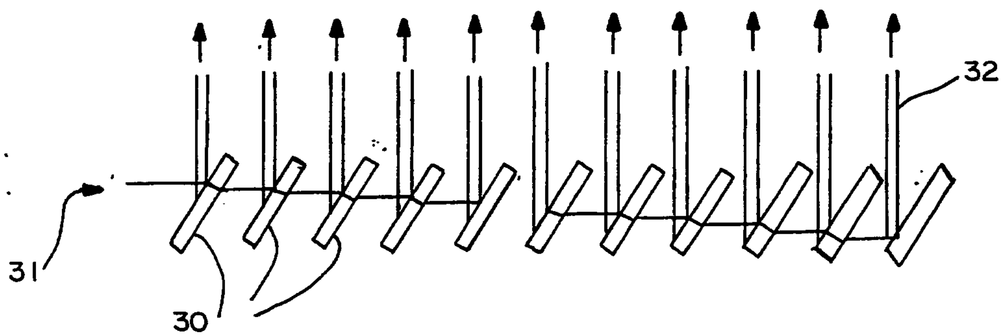

FIG. — 2B

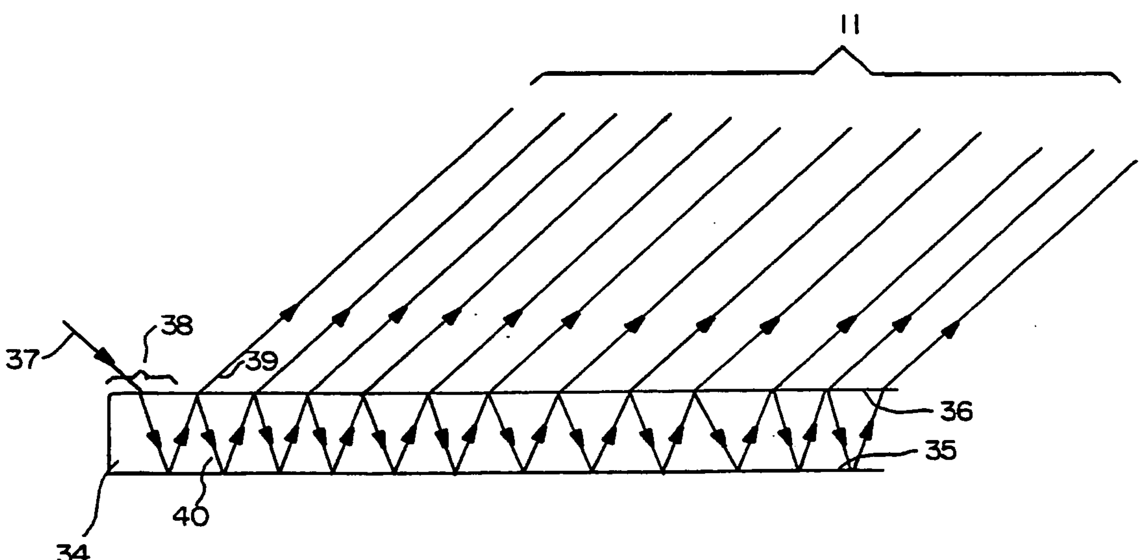

FIG. — 2C

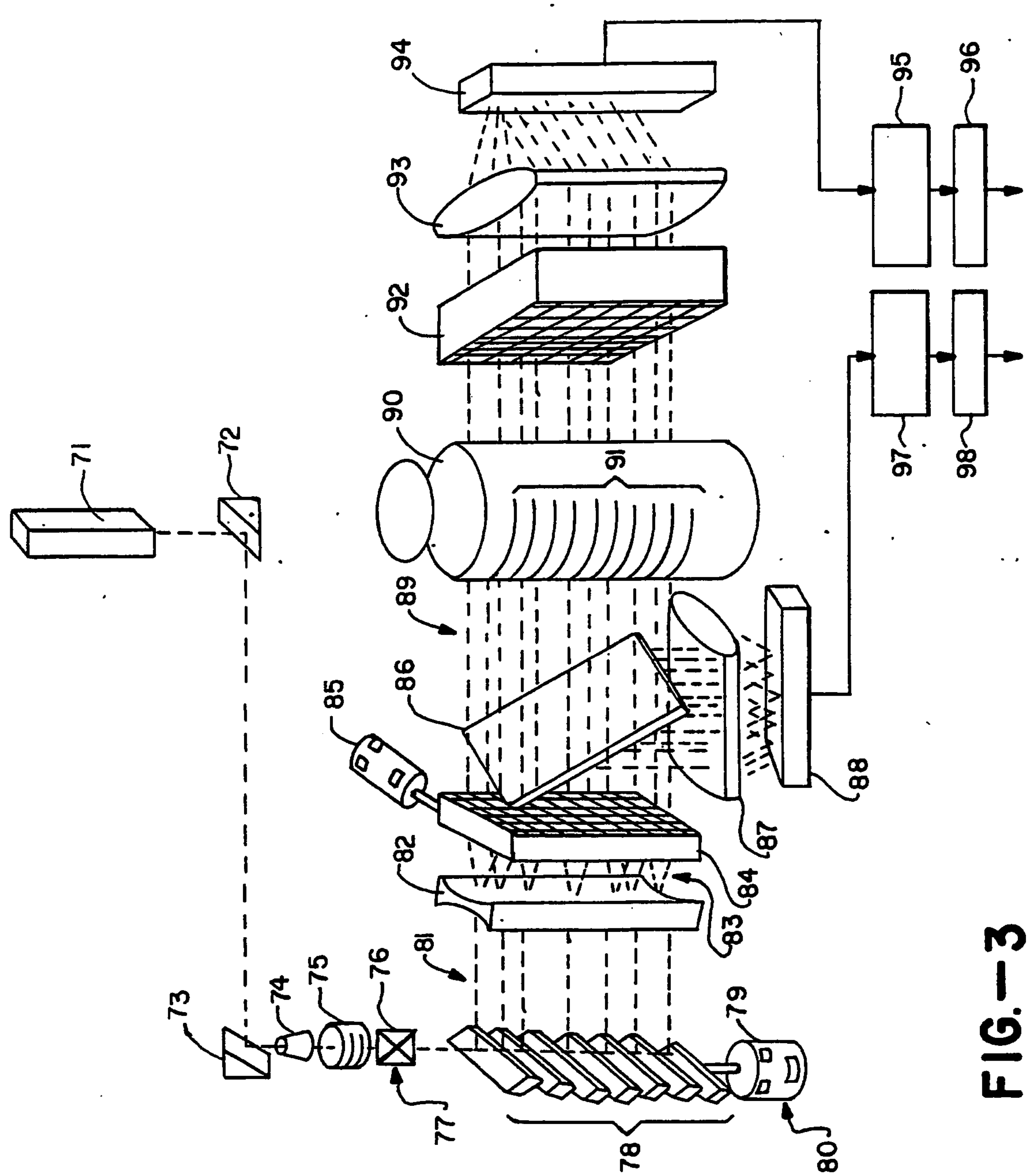
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FIG.—3

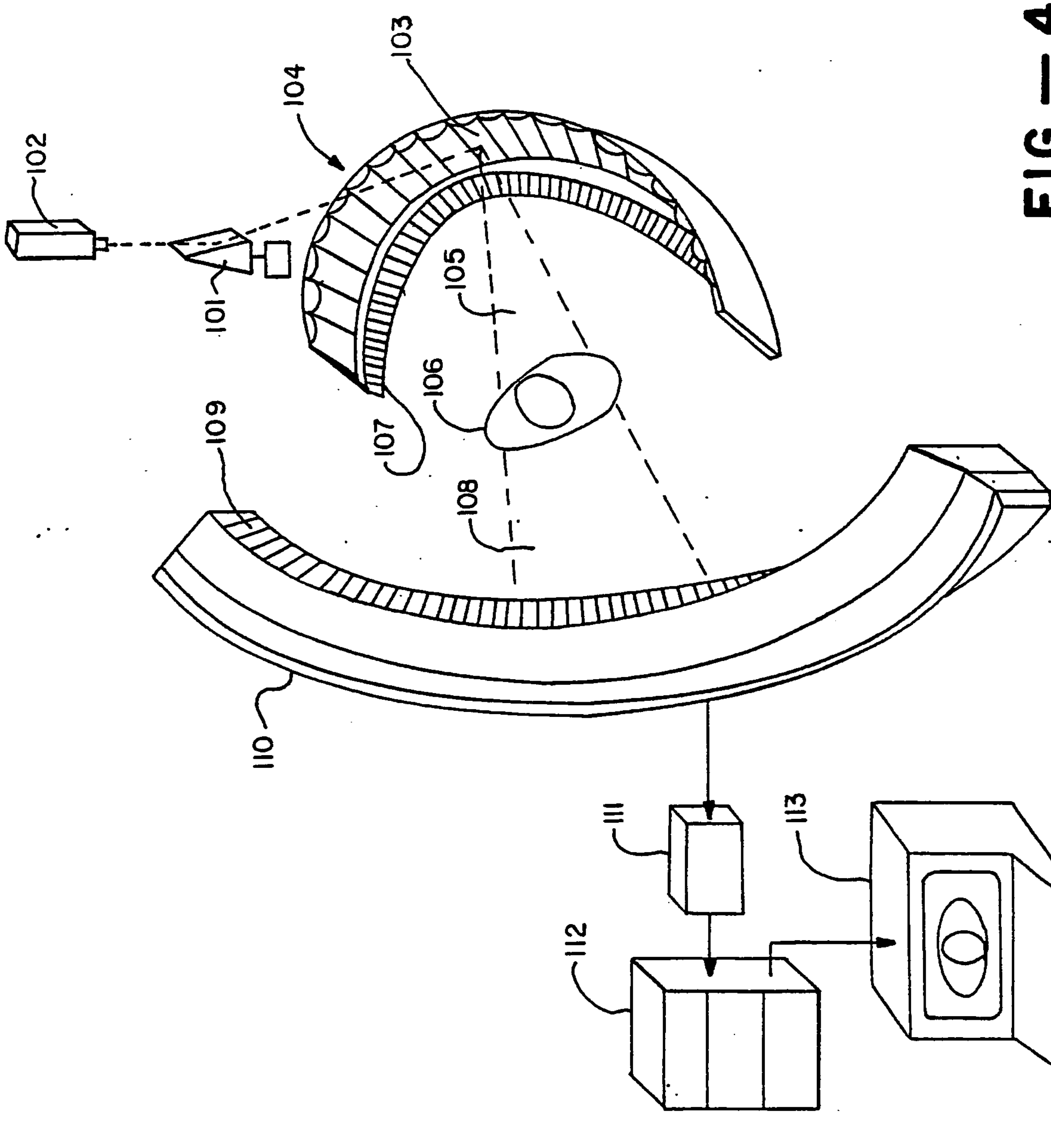

FIG. — 4